METEORITE INFALL AND TRANSPORT IN ANTARCTICA: AN ANALYSIS OF ICEFIELDS AS ACCUMULATION SURFACES.

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Over 10,000 meteorite fragments have been collected on only a dozen or so small icefields in Antarctica. The terrestrial history of these meteorites is important, both from the perspective of the effects of their ambient environment on the meteorites themselves, and on the information that can be derived in relation to ice flow and ice stability over periods of time up to 1 million years. We discuss the relative importance of meteorite infall, and ice and aeolian transport in creating meteorite accumulations and the importance of ice and aeolian transport and weathering in removing meteorites at various icefields in Antarctica. The present analysis is confined to equilibrated ordinary chondrites. We use the natural thermoluminescence (TL) to analyze infall and induced TL to examine the effects of weathering. Natural TL is used in combination with size analysis to guage the effects of aeolian transport. Some icefields, especially the Lewis Cliff Ice Tongue, are dominated by wind-transported fragments, while others, including the Far Western field at Allan Hills, have lost fragments. It appears that most Antarctic icefields preserve meteorite collections on time scales of a few tens of thousands of years.

Introduction. Blue ice fields are fairly common in Antarctica [1], but only a few hold significant numbers of meteorites. It was first suggested that meteorite-bearing icefields were associated with substantial ice flow barriers [2], while the meteorite-barren fields were products of aeolian erosion. Thus, meteorite-bearing icefields are the result of ice rising to the surface and evaporating, leaving entrained meteorites on the surface [2]. An additional source of meteorites was presumed to be direct infall onto the surface of the icefield. Later, it was shown that wind could transport meteorites <100 g [3], thus raising the possibility of wind-deposited meteorite accumulations. The relative importance of infall and ice and wind transport in producing meteorite accumulations is typically uncertain at any given icefield [3,4].

It is often presumed that at least some of the meteorite-bearing icefields are stable surfaces on timescales of up to a million years, the oldest meteorite terrestrial ages [2]. This suggestion is perhaps supported by recent surface exposure dating [5]. However, it has likewise been suggested that at least some icefields are dynamic surfaces whose current state reflects climatic conditions over only the past hundred thousand years or so [4,6].

In the present paper we examine the relative importance of addition and loss mechanisms at some Antarctic meteorite accumulations, using mass distributions and induced and natural TL data.

Data Sources. In our analysis we use the terrestrial age estimates of Nishiizumi *et al.* and Michlovich *et al.* [7], based on ^{36}Cl and ^{14}C activities. We use sample masses from the compilation of Grossman [8]. Natural thermoluminescence (TL) data are also summarized in [8]. Induced TL data are given in [9].

Discussion. The relative importance of processes that lead to meteorite accumulation and those leading to losses can be evaluated using a variety of techniques. On the loss side, degrees of weathering at various icefields can be evaluated by a variety of techniques, including induced TL sensitivity [10]. Infall can be evaluated using natural TL, with meteorites with high natural TL levels being candidates for recent fall [9]. Aeolian transport should be apparent in meteorite size distributions, with small, light meteorites being more susceptible to transport than larger meteorites [3]. Transport within the ice is the most difficult factor to evaluate, since ice, unlike wind and water, is fairly unselective in sizes of objects moved and leaves few measureable effects.

There are significant differences in degree of weathering of the meteorite populations at various icefields (*e.g.*, Fig. 1). In Table 1 we list the abundance of samples at each icefield with TL sensitivities similar to those of modern falls, and hence the least weathered. We find that the least weathered collection of meteorites is found at Elephant Moraine, while at most other icefields about 50% of meteorites are significantly weathered. The meteorite collections from the Upper and Lower Ice Tongue at Lewis Cliff are dominated by highly weathered meteorites. While this might suggest that the Ice Tongue meteorites have experienced long periods of time on the ice surface, it appears that weathering can occur very rapidly under certain climatic conditions [10]. However, even the most weathered Antarctic meteorites are relatively fresh compared to meteorites from hot deserts, and it thus unlikely that a significant proportion of the Antarctic meteorites have been lost through weathering alone.

Mass distributions for meteorites collect on the icefields of Antarctica are often log-normal. Aeolian transport should produce a smaller average size if meteorites are added, or a larger average size if meteorites are lost by wind transport. At three icefields, the Lower and Upper Ice Tongue and Meteorite Moraine at Lewis Cliff, the average mass is around 10 g, and it is thus likely that these collections are dominated by wind-deposited meteorites. The Upper Ice Tongue has a slightly larger average mass than the Lower Ice Tongue. Meteorites from Elephant Moraine average about 40 g, with meteorites >100 g fairly abundant. We suggest that wind transport is a neutral process at this field, adding as many meteorites as are removed. The Far Western and Near Western and the MacAlpine Hills icefield exhibit broad mass distributions, with a high abundance of meteorites >100 g. We suggest that, at these icefields there has been a net loss of meteorites through wind transport. The Allan Hills Main icefield has two peaks on a log distribution plot, having many

samples with masses of ~10 g. This suggests that small meteorites have been added by wind transport to a pre-existing collection dominated by large meteorites, in accord with the suggestion of Delisle and Sievers [3].

We use the ratio of meteorites with high and low natural thermoluminescence (TL) levels, defined as >60 and <20 krad, respectively (Table 1). Modern falls exhibit a range of natural TL and a ratio of 0.36. Most icefields exhibit ratios similar to modern falls, suggesting that most of their meteorites have not been exposed on the ice surface for more than 100 ka [11]. The two exceptions are the Allan Hills Main icefield and the Upper Ice Tongue at Lewis Cliff, both of which have a high abundance of "Low TL" meteorites.

Huss [4] used mass distributions to estimate "accumulation times" for various icefields, based on the assumptions that all meteorites were placed on the field by direct infall and that the icefield was essentially the same size throughout its history. Obviously, given the importance of aeolian transport at many icefields and the unknown importance of ice transport, this is a simplistic assumption. Huss [4] found that , with the exception of the Allan Hills Main icefield, accumulation ages are generally on the order of ten thousand years or so. Meteorites with high natural TL are candidates for recent direct infall, and, since these samples tend to be large (>20 g) due to sampling constraints, the number of such meteorites is arguably a better estimate of new falls. Applying these data, and an estimate of infall flux, we find that icefields have apparent accumulation times of between 1,000 to 30,000 years (Table 1).

Conclusions. Our data suggest that there is considerable diversity in meteorite concentration/loss mechanisms between icefields in Antarctica. The Lewis Cliff Lower Ice Tongue and Meteorite Moraine are dominated by wind-deposited fragments, probably exposed on the ice surface within the last few tens of thousands of years. The Upper Ice Tongue at Lewis Cliff, while also probably dominated by wind-deposited fragments, contains a significant proportion of meteorites with surface exposure ages >100 ka. In agreement with the suggestion of Delisle and Sievers [3], we suggest that about half of the meteorites at the Main icefield at Allan Hills were aeolian deposited but with a significant contribution from infall or ice transport. The Far Western Icefield at Allan Hills has apparently lost meteorites through aeolian transport. Elephant Moraine and the MacAlpine Hills icefield are probably the most temporary of icefields in the current study, bearing mostly unweathered meteorites with low apparent surface exposure ages.

These data suggest that for the most part meteorite "stranding" surfaces are temporary, storing meteorites 100,000 years or less. Meteorites with terrestrial ages in excess of 100 ka have probably spent the remainder of their terrestrial histories buried in the ice, or possibly have been "recycled" through previous generations of icefields.

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[1] Takahasi *et al.* (1992) *Proc. NIPR Polar Meteor. Glac.* 5, 128. [2] Whillans and Cassidy (1983) *Science* 222, 55. [3] Delisle and Sievers (1991) *J. Geophys. Res.* 96, 15577. [4] Huss (1990) *Meteoritics* 25, 41. [5] Nishiizumi *et al.* (1991) *EPSL* 104, 440. [6] Delisle (1993) *J. Glac.* 39, 397. [7] Nishiizumi *et al.* (1989) *EPSL* 93, 299; Michlovich *et al.* (1995) *JGR* 100, 3317. [8] Grossman (1994). [9] Benoit *et al.* (1992) *J. Geophys. Res.* 97, 4629; Benoit *et al.* (1993) *J. Geophys. Res.* 98, 1875; Benoit *et al.*, (1994) *J. Geophys. Res.* 99, 2073. [10] Benoit *et al.*, this meeting. [11] Benoit P.H. (1995) *Quat. Sci. Rev.* 14, 531.

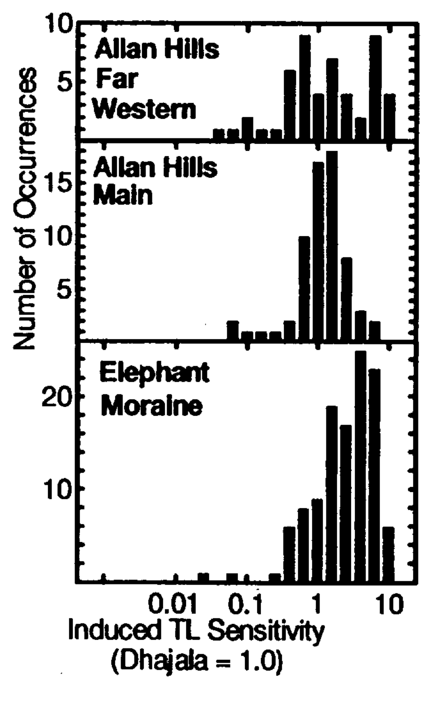

Fig. 1. Induced TL sensitivity distribution for equilibrated ordinary chondrites from various icefields of Antartica.

Table 1. Terrestrial history constraints for meteorites on various blue ice fields of Antarctica. See Grossman [8] for locality map. Some data for modern falls shown for comparison.

			Accumulation Time (10^3 yrs)	
	% Least weathered+	Low TL/ High TL	High TL meteorites	Based on total mass*
Elephant Moraine	77%	0.4	6	28.5
Allan Hills Region:				
Main	48%	2.5	2	>144
Farwestern	51%	0.8	1	5.4
Lewis Cliff Region:				
Meteorite Moraine	19%	0.4	25	11.0
Upper Ice Tongue	19%	1.1	11	17.0
Lower Ice Tongue	27%	0.3	26	10.0
MacAlpine Hills	43%	0.3	30	62.0
Queen Alexandra Range	53%	0.5	2	--
Modern Falls		0.36		

+Based on induced thermoluminescence sensitivity [10].
*Some estimates from Huss [4].